Field Testing and Dynamic Model Development for a Mars Tumbleweed Rover

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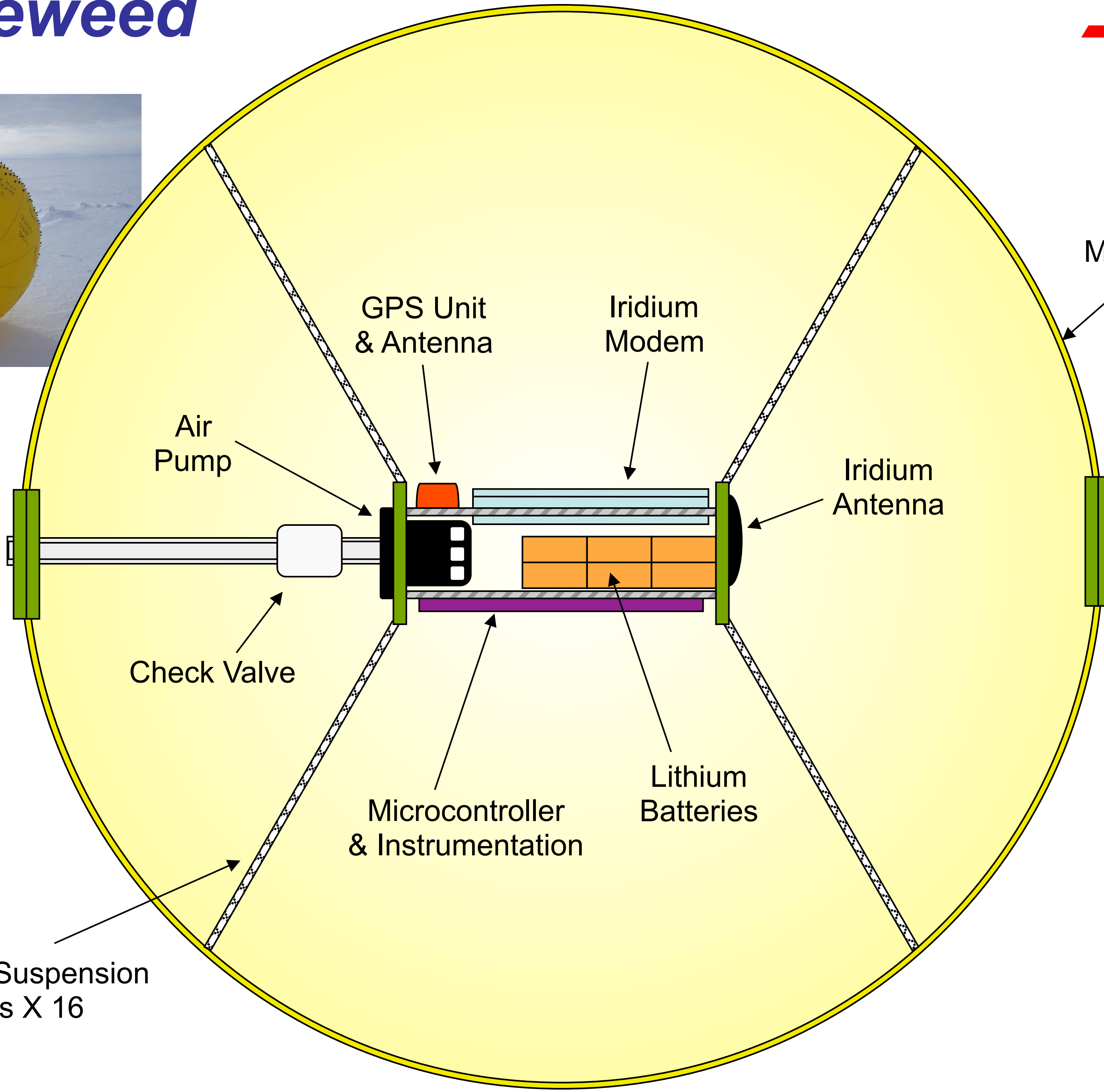
Tumbleweed

Polar Rover



Not to scale

Tumbleweed Landing System Tested in Antarctic Instrument Deployment

Rutford Ice Stream Location

Rutford Ice Stream Camp Setup

Air Drop Components

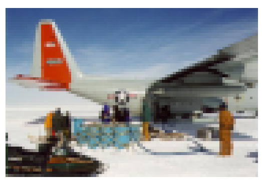
Tumbleweed Air Drop Deployment Test

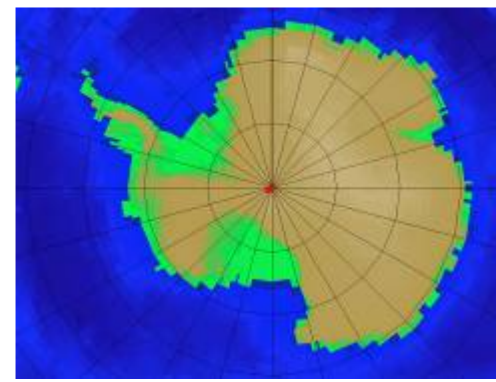
Tumbleweed Rover Deployments

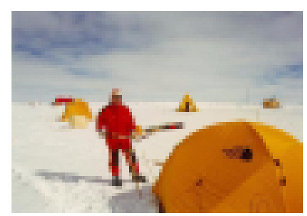
Greenland
- August 2003
- 131 km
- 9 days

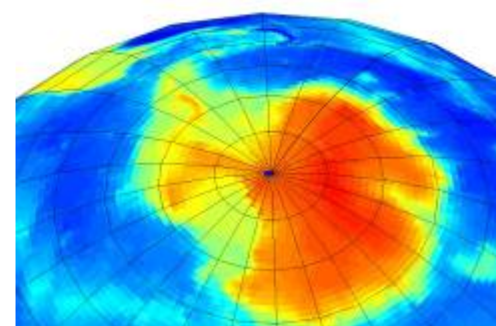
South Pole
- January 2004
- 134 km
- 7 days

Greenland 2
- May 2004
- 200 km
- 7 days



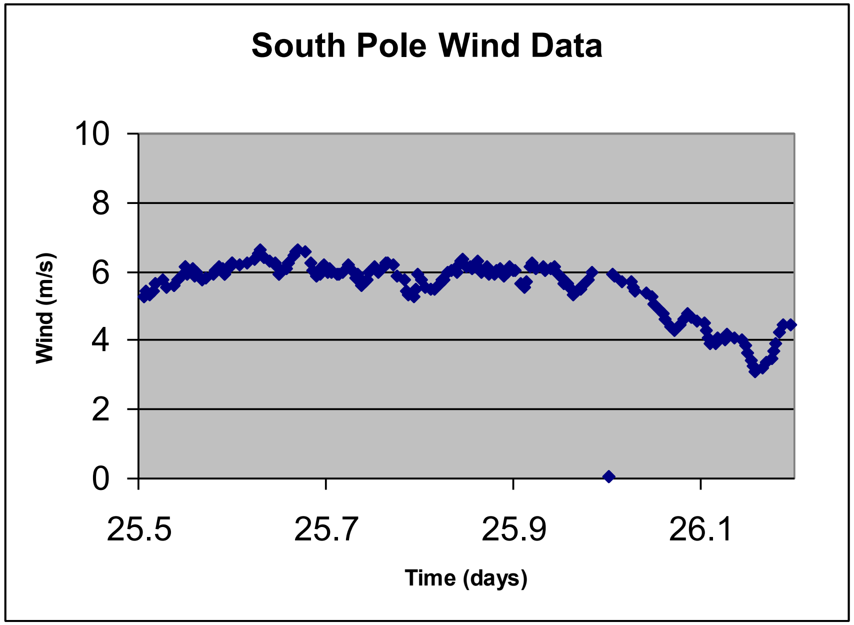


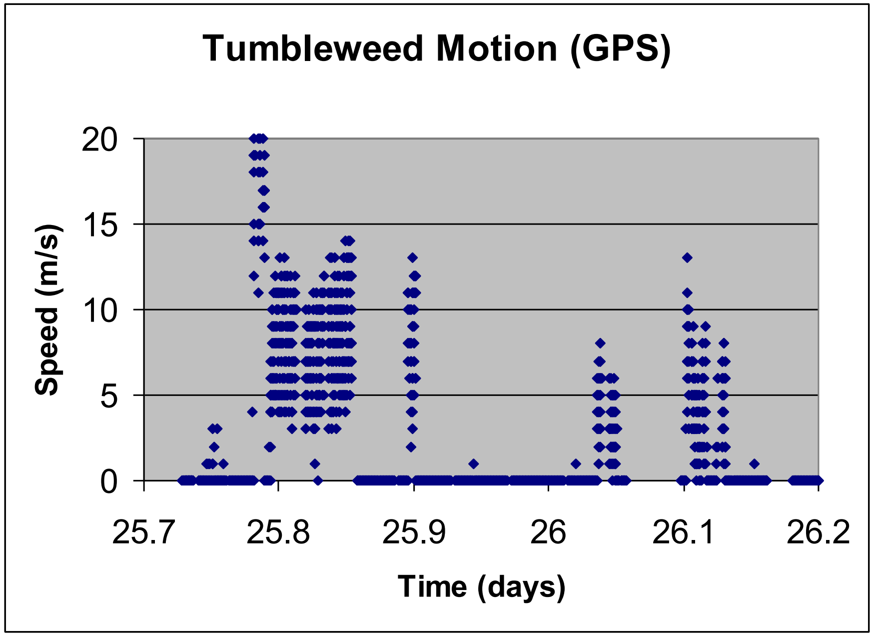




Wind Response

- Displacement of vehicle from launch point means wind data and vehicle speed rapidly decorrelate : difficult to evaluate performance as fn(wind). Some indication that thresholding or other effects mean motion won't correlate anyway....

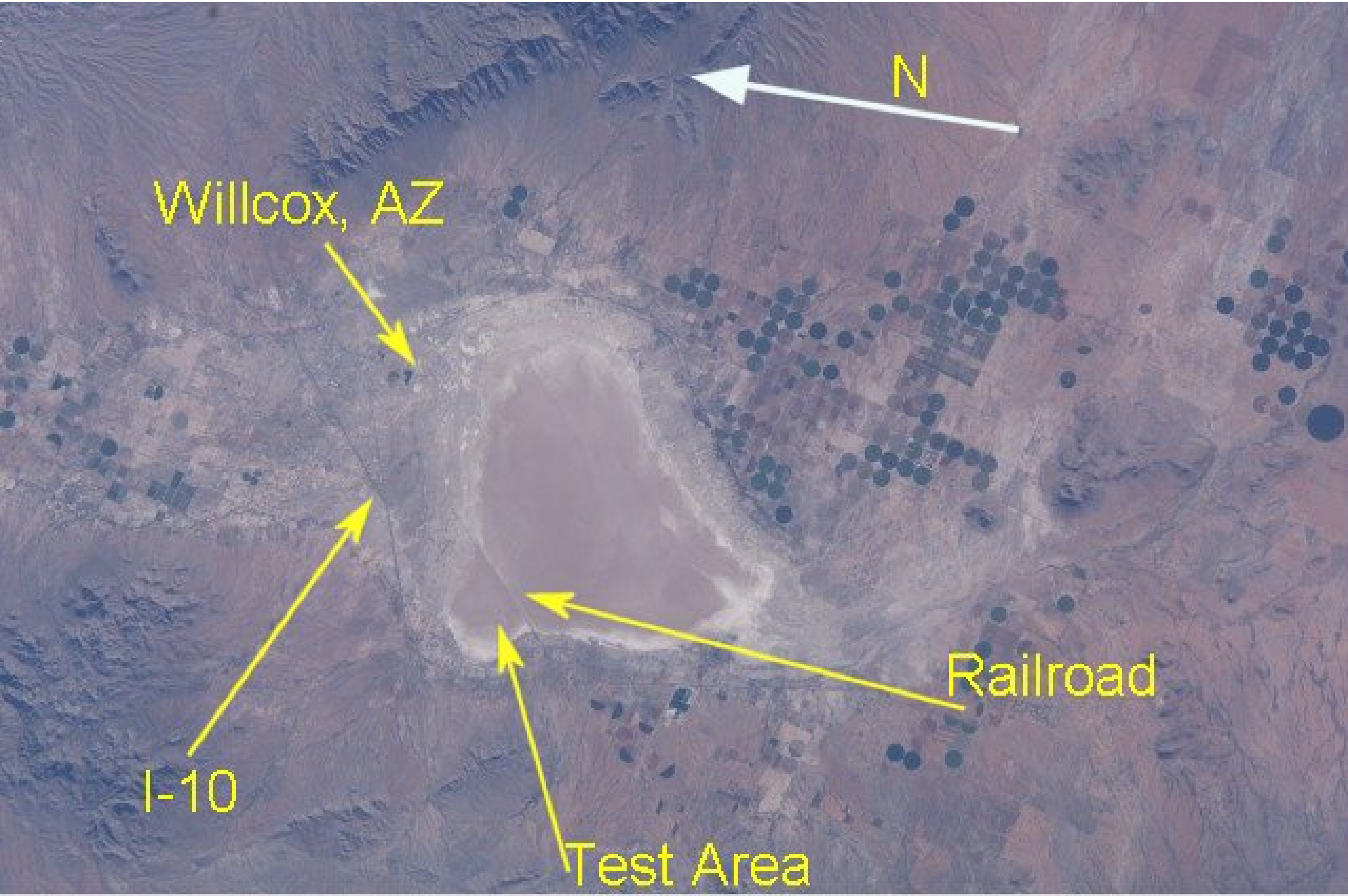




2006 Arizona Field Tests
Supported by JPL DRDF

Objective - Conduct trials where high-time-resolution record of the tumbleweed motion can be correlated with concurrent, local wind environment data

Tests conducted at Willcox Playa, AZ : large area with low aerodynamic roughness (no vegetation), reasonable proximity to U. Arizona



ISS009E05677

Wind Environment documented with

-triple anemometer array (boundary layer height/ aerodynamic roughness)

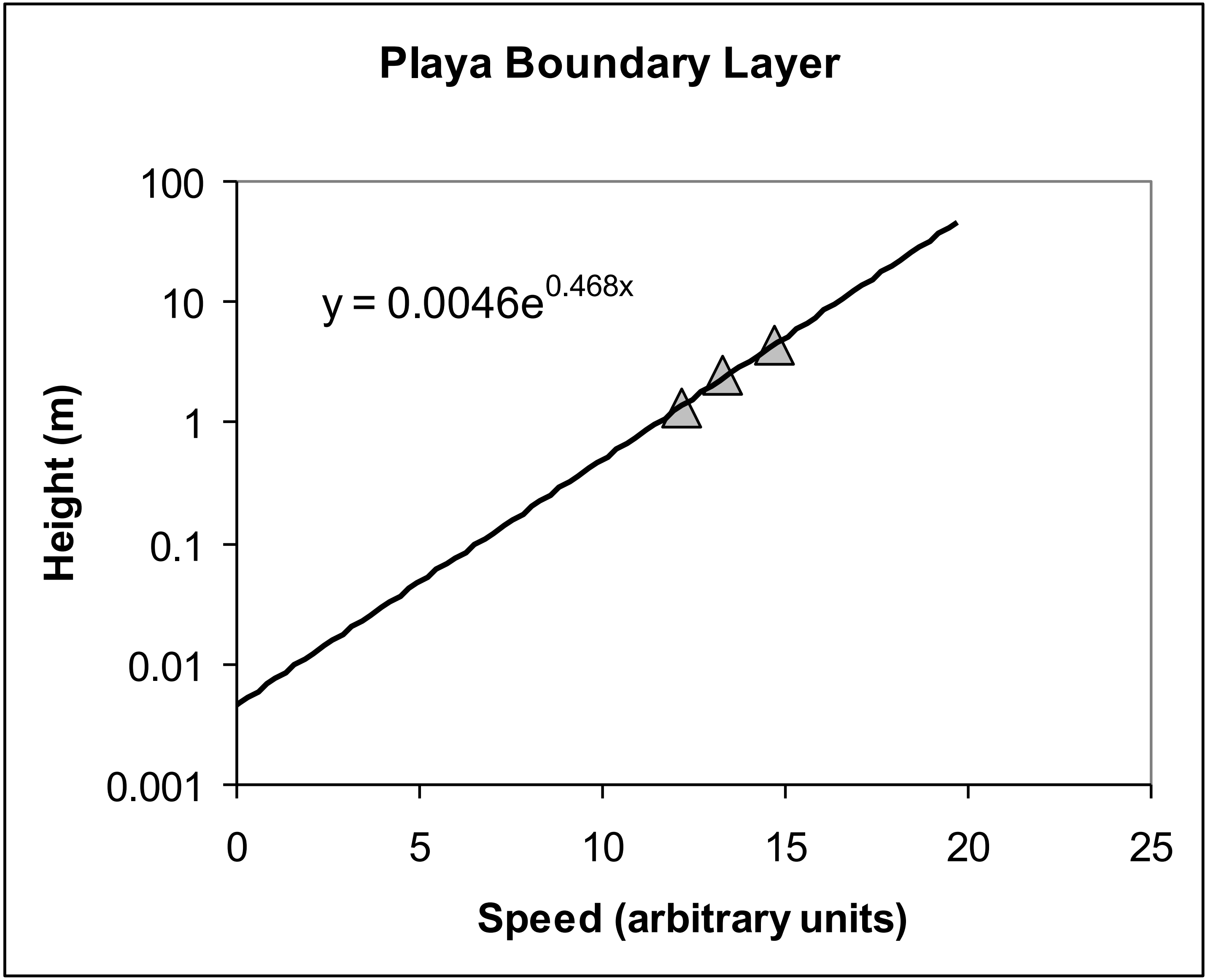
- regular anemometer

- handheld anemometer as backup

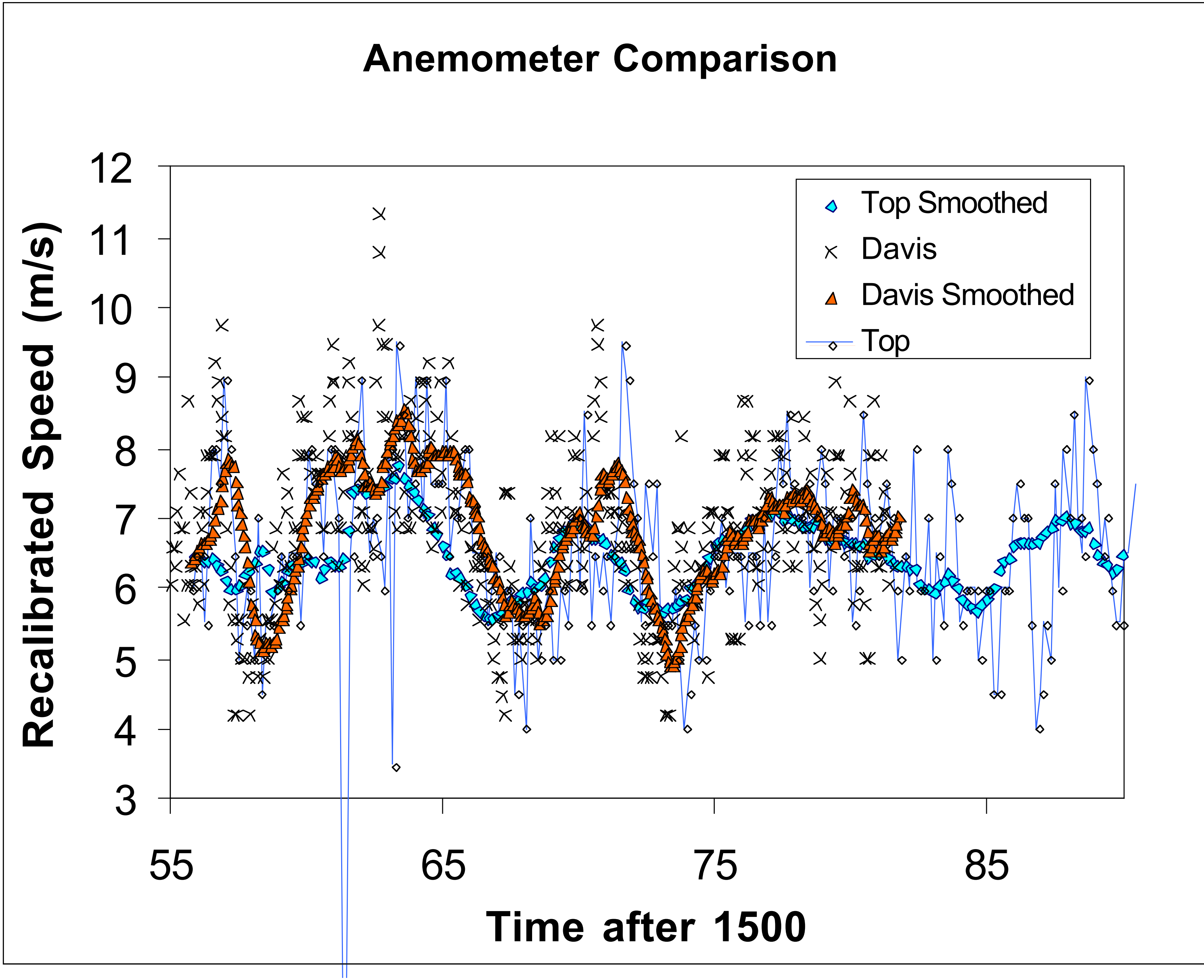
-GPS readings recorded onboard

- external video camera

(Intro Movie)



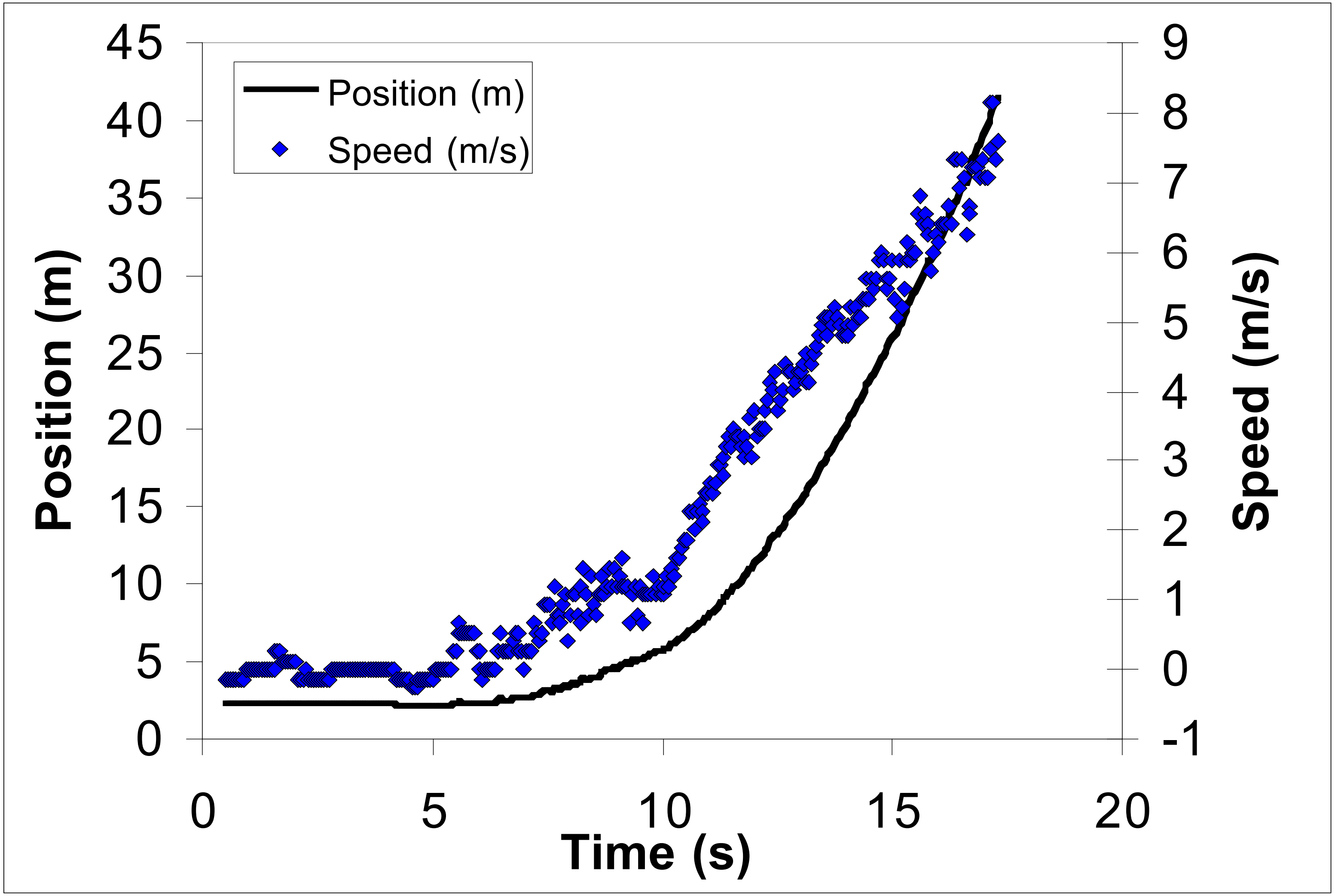
Windspeed measurement at 3 heights confirms wind to follow Prandtl (logarithmic) boundary layer profile. Aerodynamic roughness is very small ~0.5cm, as to be expected on very smooth playa



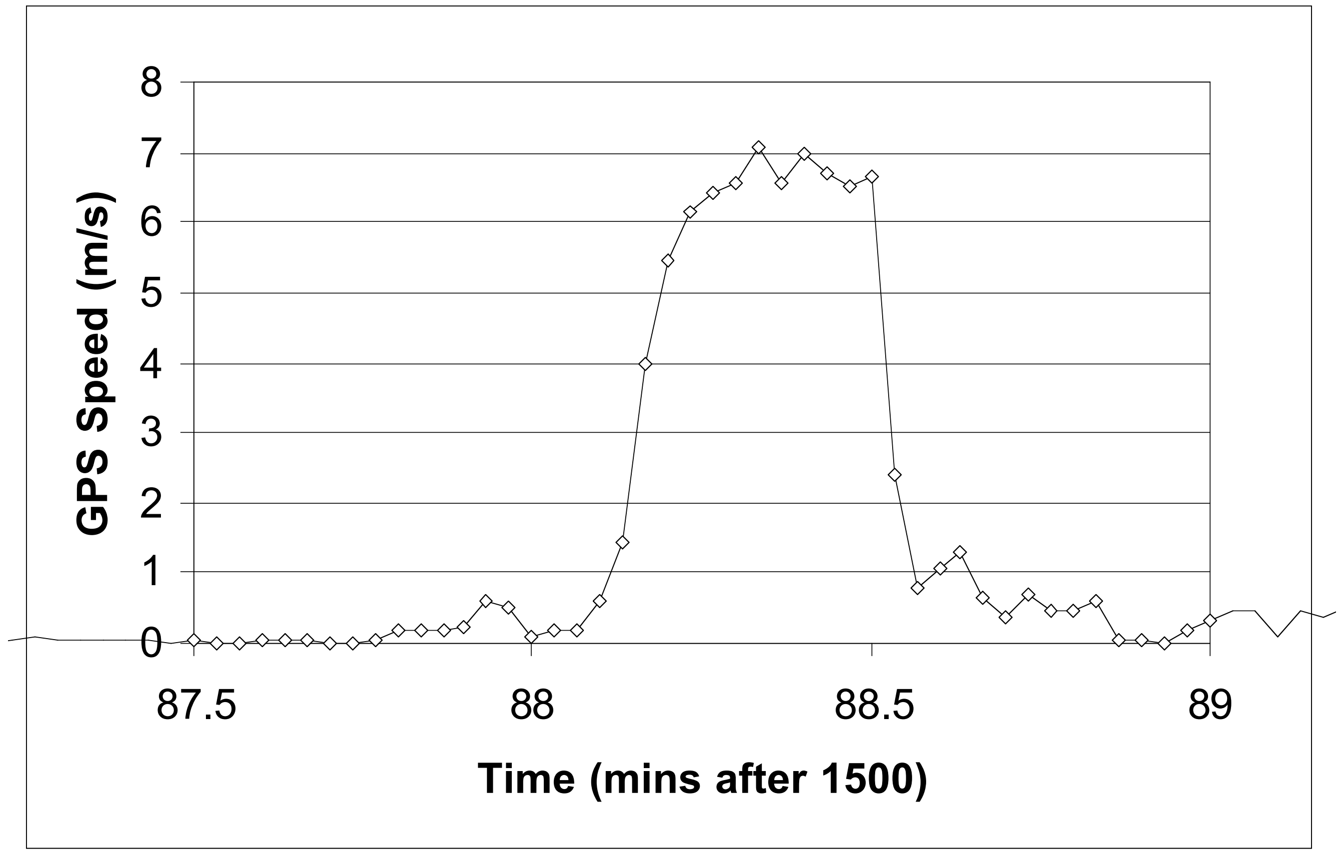
Anemometer Comparison
Recalibrated Speed (m/s)
12
11
10
9
8
7
6
5
4
3
55
65
75
85
Time after 1500
Top Smoothed
Davis
Davis Smoothed
Top

- test movie


fastroll.avi
253 of 636
Hi8
0:25:50
Point 51
4:26 PM
Origin 1
t = 12.60 [s]
x=24.0 y=439 (pixels)



Video record indicates first a gentle acceleration of 0-1.2 m/s in the first 4.5 seconds of motion (~ 0.027g), while over the following 7 seconds the acceleration is much higher (0.09g), reaching 7.5 m/s



Video record agrees with GPS speed record. Video has higher time resolution, but requires more effort.

Knowing mass properties of Tumbleweed and acceleration, taking the cross-section area as 2.6 m^2, and air density as 1.1 kgm^2, (Willcox Playa is at 4100ft elevation) the drag coefficient for the faster phase of motion is therefore 0.14.

However, if the vehicle is rolling without skid, as was apparent in the video, then the drag force coefficient must be augmented by 30% to yield Cd=0.19 (since rotational kinetic energy is being supplied)   The slower speed segment indicates a slightly smaller drag coefficient after rotation correction of Cd=0.14

At a flow speed of 2 m/s, the Re~ 2.4×10^5, Cd~ 0.4, while at 7 m/s, Re~ 8.4×10^5 (turbulent) and Cd~ 0.1.

Thus drag is consistent with smooth sphere (minimal boundary layer effect here), which is rather low..

Bounce dynamics need to be better understood. In principle more ground drag than rolling, but bounce gets out of boundary layer and into more energetic wind…?

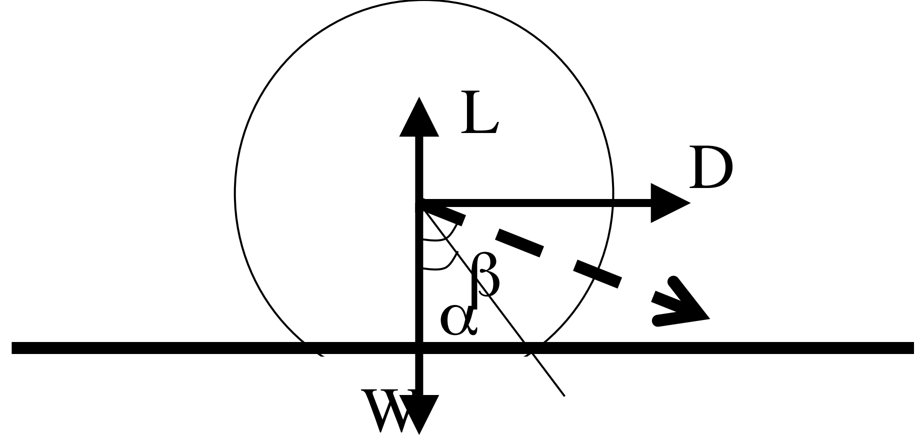
(Bouncing Movie)

We took the opportunity to study the motion threshold of *Salsola Kali* the organism that inspired this biomimetic vehicle…

NB - real tumbleweeds have asymmetric mass/area distribution - a function of how an organism can feaibly grow, or is it natural selection, actually better for rolling?

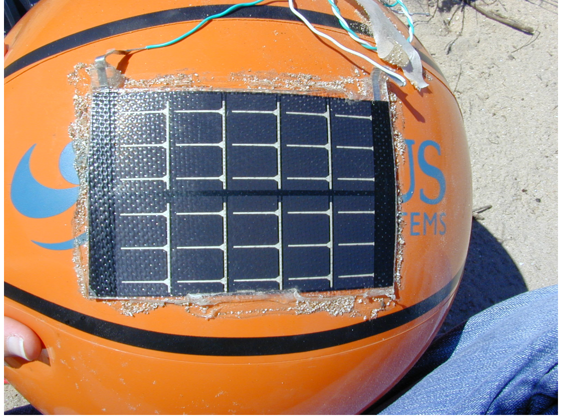
Threshold windspeed for rolling motion depends on inflation of Tumbleweed.

(as well as, presumably, on roughness)

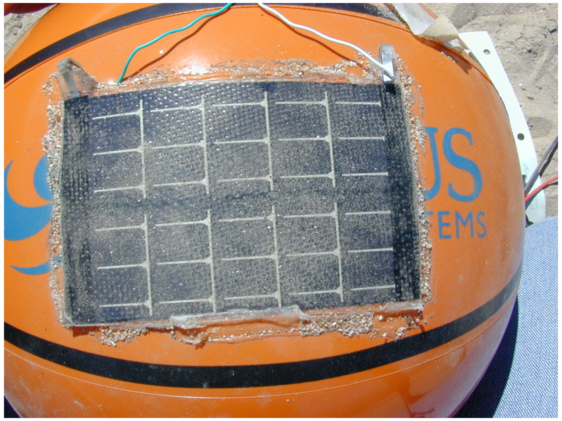


Level of inflation %	Wind speed m/s
100	4.5
80	5.5
70	7.0
50	9.5

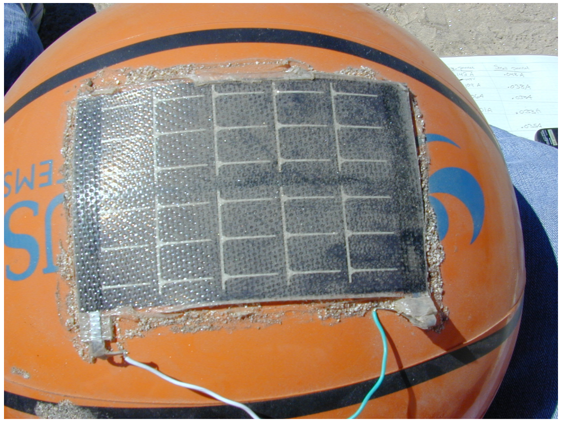
start



30m

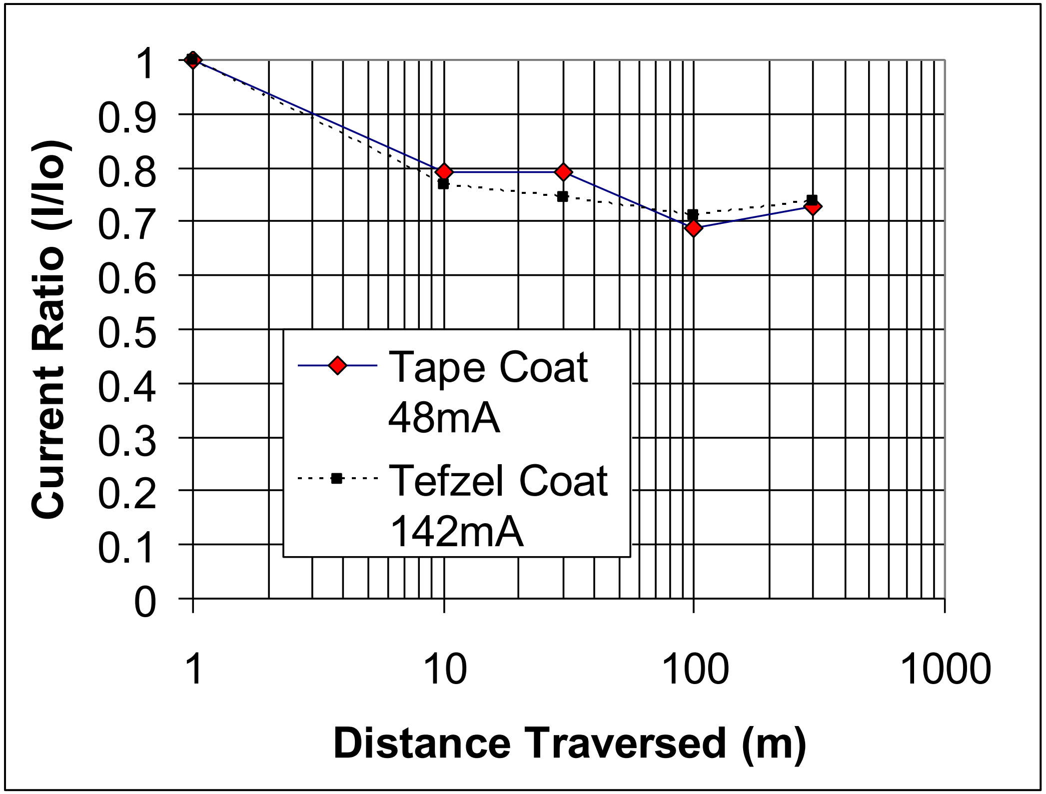


300m



What about flexible solar panels on skin ?

Not enough testing to explore scratch/ abrasion, but dust adhesion at least becomes self-limiting....



Conclusions

Obtaining high-fidelity environment data synchronized with observations of motion is essential to understand dynamics properly.

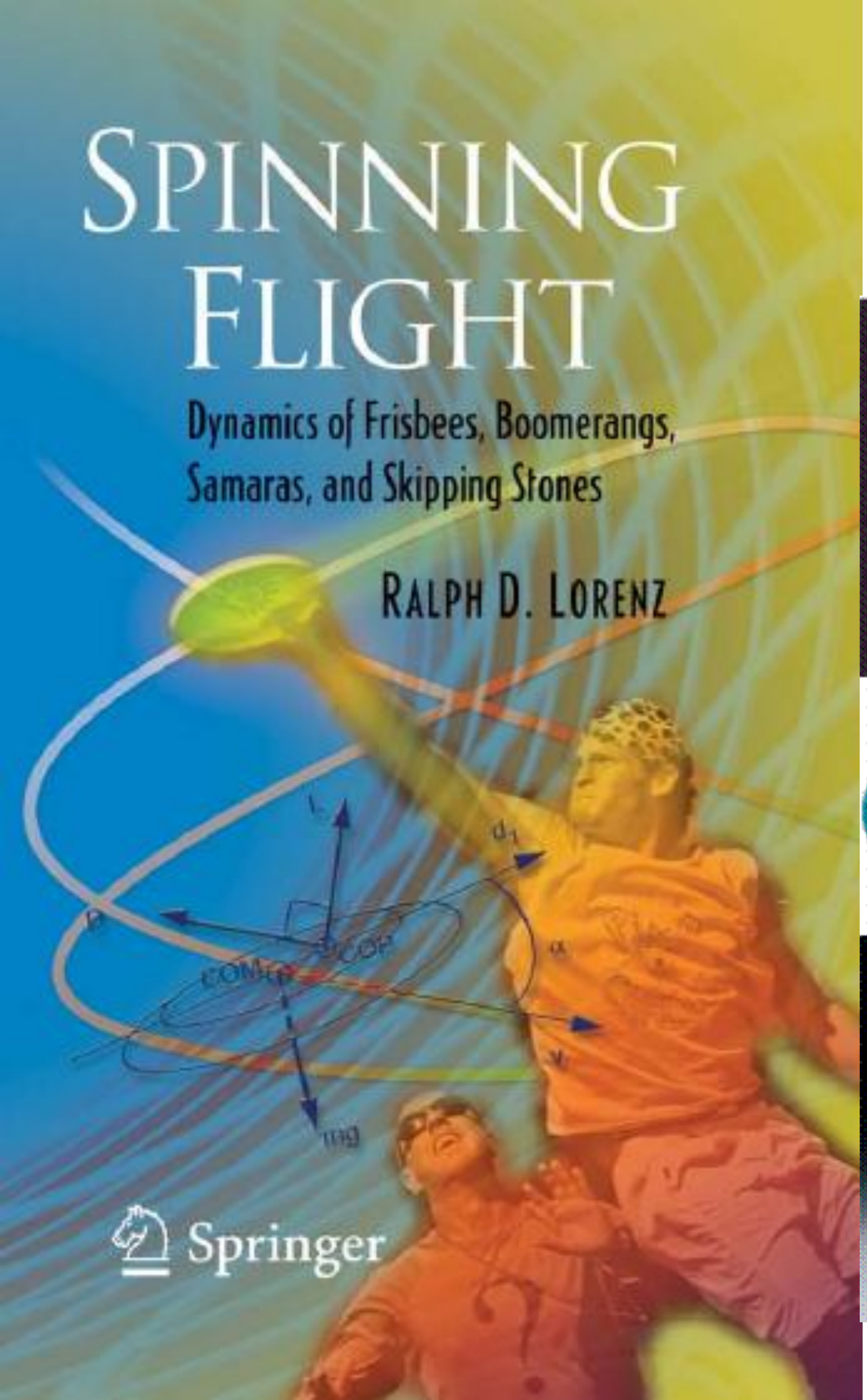
Focussed (3 day) field campaign obtained desired data.

Smooth sphere may be poor at extracting momentum from the wind (already noted in previous studies) - real tumbleweed have a much higher effective drag coefficient.

Onset of bounce, partitioning between rotational and translational kinetic energies not yet understood.

Future investigation should contrast playa with rocky area - effects both on rolling threshold and friction, and on boundary layer thickness.

Dust coating not a problem for flexible surface solar arrays.



Learn more about Tumbleweeds and other spinning things in 'Spinning Flight' - due out next month!